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Optimizing the Efficiency of Eggplant Fruits Harvesting and Handling Machines

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Authors' contributions

This work was carried out in collaboration between both authors. Author HU designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author NEN managed the analyses of the study and literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The knowledge of the mechanical properties of agricultural products plays an essential role during the design, development, programming and utilization of their automated harvesting, handling and processing machines. The aim of this study was to investigate the influence of field practices (pre-harvest treatments) on some mechanical properties of eggplant (*Solanum aethiopicum* L.) fruits, necessary for the automation of agricultural production. Eggplant (cv. Djamba) was cultivated in the field trial, in four different treatments mediums, which were: Zero amendment (also referred to as the control), organic manure, potassium nitrate (KNO_3) and combination of organic manure and KNO_3. The eggplant fruits were harvested at peak maturity (35 days after flowering), and their mechanical properties tested, according to standard procedures. Results obtained revealed that field practices had a significant ($p \leq 0.05$) effect on all the mechanical properties investigated. The fruits produced by using the combination of organic manure and KNO_3 had superior mass, when compared with other treatments options. The control fruits exhibited the poorest failure force (305.58 N) and failure energy (3.895 Nm); while the fruits cultivated with the combination of organic manure and KNO_3 had the highest failure force and failure energy of 636.6 N and 5.312 Nm

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respectively. The study revealed that the fruits produced with organic manure exhibited superior failure force and failure energy, compared to the fruits produced with KNO_3. Additionally, the fruits produced by using organic manure, exhibited the highest deformation (24.01 mm) at failure point; while the control fruits recorded the lowest deformation (18.8 mm). Regarding the puncture properties, the tissues of the fruits produced with organic manure had the least resistivity to puncture force (50.30 N); which was lower than the puncture force of 65.73 N recorded by the control fruits. The highest resistance to puncture force (89.17 N) was observed in the fruits cultivated with KNO_3. These results will help to optimize the efficiency of eggplant fruits harvesting and handling machines; thereby reducing the rate of mechanical damage being done to the harvested products.

Keywords: Eggplant; field practices; optimization; organic manure; potassium nitrate.

1. INTRODUCTION

Eggplant (*Solanum aethiopicum* L.) is one of the commonly cultivated horticultural crops in the world. Apart from the fruits, the leaves are consumed as a vegetable. Eggplant fruits production had increased recently, due to their experimentally verified medicinal and nutritional properties [1]. According to the Food Agriculture Organization (FAO) statistics, about 9 million tons of eggplant fruits were harvested from 2 million hectares (ha) in 2018; which was higher than the 5 million tons of eggplant fruits produced from 1.9 ha in 2014 [2]. Several eggplant varieties including, *Bello, Cubanita, Yalo, DJamba, Africa beauty, Kotobi, N'Goya, Scorpio, Oscar, Tango*, *Scorpio, Oscar, Epic, Tango*, *Aliona,* etc. are cultivated globally [3]. These varieties displayed different traits; such as corolla diameter, fruit weight, fruit size and shape, leaf area, fruit colour, maturity age, nutrient content, etc. [4]. Eggplant fruit contains a large proportion of carbohydrate, crude fibres, calcium, iron, carotene, vitamins B1, B2, B6 and ascorbic acid [5]; therefore, increasing its chances of combating malnutrition, in under-aged children and invalid adults. The fruits contain flavonoids which help to remediate the toxic effects of low density lipid (LDL) in human blood [6]. The fairly high concentration of ascorbic acid, phenols, anthocyanin, glycoalkaloids and α-chaconine in eggplant fruits and leaves increased its' pharmacological potentials [7].

According to FAO, most of the agricultural products wastage occurred due to mechanical damage during harvesting and post-harvest handling operations [8]. During harvesting and post-harvesting unit operations, agricultural products are exposed to several mechanical forces; mainly, compression, puncture, flexural and tensile forces. If these forces exceeded the amount the plant's cellular structures can absorb, lead to their disruptions [9]. This microstructural cellular disruption (mechanical damage), exposed the agricultural product to rapid deterioration and diseases attack. Apart from mechanical damage that occurred during the harvesting and post-harvesting operations of agricultural products, FAO has identified late harvesting and processing of the products, as another major factor that is contributing to the 40% food wastage globally [8]. Citing Wang et al [10], manual harvesting and packaging of agricultural products are very tedious, wasteful, and time consuming, making large scale agricultural production practically difficult; therefore, making robotization of the agricultural industries inevitable.

Replacing human labour with mechanized labour, to increase agricultural production and food security has become a key issue nowadays, due to the growing world population [11]. Recently, numerous scientists have studied the mechanical properties of various agricultural products, under several farming methods, plants varieties, climatic conditions, etc., to design and develop variously mechanized or automated crops harvesting, handling and processing machines/systems. An automated cucumber fruits harvester was designed and developed by [11], using the physical characteristics and optical properties of cucumber fruits. The automated machine used the correlation relationship between the cucumber fruit mass and volume, to determine the maturity state of the fruit. Wang et al [10] also designed an automated greenhouse tomato fruits harvester, with efficiency of about 86%. The robot used the some optical and mechanical properties of the tomato fruit, to harvest and conveyed the harvested fruits, to the collection point. Hayashi et al. [12] used machine vision technology to design and construct an automated eggplant harvesting machine and observed that the eggplant's fruit size was a necessary factor, in order to increase the machine efficiency. These machines were developed to optimize the harvesting and handling operations, in order to achieve superior and safer agricultural products. Despite the several breakthroughs in the mechanization of agricultural production, there are still a lot of obstacles that automated harvesters usually encountered, during the harvesting and handling operations. Therefore, it is necessary to take care of all the challenges during the design, development and application of these machines and equipment [13].

In order to fully mechanized and robotized agricultural production; intensive researches are ongoing, on the effect of field practices and environmental conditions, on the engineering properties of agricultural products. Mechanical properties of the plants fruits, seeds, nuts, roots, cane, vine, leaves, stems/stalks, etc. are some of the crucial factors to be considered, during the design, development and programming of their automated harvesting machines [10,14]. Several researchers [9,15,16,17,18] had investigated the effect of farming method on the physico-mechanical properties of agricultural products. They observed that both organic manure and inorganic fertilizers highly improved the physico-mechanical properties of agricultural products. In addition, earlier research results experimentally established that the maturity stage of agricultural products greatly influenced their mechanical properties; either the mechanical properties will decline as the product matured, or declined as the product matured. Oghenerukevwe and Uguru [19] investigated some physical characteristics of common bean (*Phaseolus vulgaris* L.) seeds during maturation, and the observed that all the parameters (size, shape and weight) investigated, increases as the bean seed matured. Furthermore, Uguru et al. [20], reported that the rupture force, rupture energy and rupture power of common bean (cv. Butter) seed, tested under quasi-statically compression, increased significantly as the bean seeds matured. This signified that the ability of the bean seeds cellular structures to absorb compression loading increases with maturity of the bean seeds.

Although, there are several literatures focusing on the mechanical properties of eggplant fruits, there is still information dearth on the effects of field practices on the engineering properties of eggplant fruits. Therefore, the specific objectives of this study were to: (i) measure the mechanical properties of eggplant (cv. Djamba) fruits under compression and puncture tests; and (ii) evaluate the effect of field practices (pre-harvest treatment) on the mechanical properties of eggplant (cv. Djamba) fruit.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Eggplant seeds

The *Djamba* F1 eggplant seeds used for this study were procured from Technisem seeds sales outlet, located at Kano State, Nigeria. Djamba is a hybrid eggplant variety, having a high production rate. According to information obtained from local farmers, *Djamba* F1 is one of the commonly cultivated eggplant varieties in Nigeria, due to its high resistance to pests and diseases; coupled with its colour, taste and high productivity.

2.1.2 Potassium nitrate (KNO_3)

This fertilizer was procured from an agro-store located at Ughelli, Delta State, Nigeria. Potassium nitrate contained two essential plant nutrients; which are nitrate (NO^{3-}), and potassium (K^+) [21].

2.1.3 Organic manure

The organic manure was formulated from the mixture of oil palm bunch waste, cattle dung and poultry waste; mixed at the ratio of 2:5:3 (by weight).

2.2 Methods

2.2.1 Nursery of seedlings

The eggplant seeds were nursed for 21 days, before they were transplanted to the main experimental plots, according to the experimental design.

2.2.2 Experimental design

The treatment was randomized in three replicates. Each plot grossly measured 3 m x 2 m, and all the plots were tilled and seed beds prepared. Six eggplants were planted in each plot at a spacing of 1 m x 1 m. The organic manure was applied at the rate of 3000 kg/ha; the KNO_3 fertilizer was applied at the rate of 200 kg/ha; while the combination of organic manure and KNO_3 was applied at the combined rate of

2000 kg/ha of organic manure and 100 kg/ha KNO_3. The organic manure was mixed with the soil at a depth of 10-15 cm, three weeks before the transplanting of the eggplant seedlings, and repeated through surface (ring) application, four weeks after transplanting. The KNO_3 was applied in a foliar form, once weekly staring from four weeks after transplanting, till when the fruits were harvested for laboratory tests. All other variables, such as rainfall, irrigation, sunlight, temperature, pests and weeds control, etc. were the same for all treatments during the growing period.

The treatments were summarized and coded as follows:

T1 = Control (zero amendment)
T2 = Pure organic manure
T3 = Pure Potassium nitrate
T4 = Combination of organic manure and potassium nitrate

2.2.3 Samples collection and preparation

The eggplant fruits were hand- picked at peak maturity stage (35 days after flowering). All the harvested fruits were inspected to remove all deformed and pests infested fruits. Then the sorted fruits were immediately taken to the laboratory for mechanical properties tests.

2.3 Mechanical Properties Tests

2.3.1 Mass determination

The mass of each eggplant fruit was direct measured by using an electronic digital balance, having accuracy of 0.01 g.

2.3.2 Compression test

Compression test was carried out on the intact eggplant fruits. The test was performed using Universal Testing Machine (Testometric model), equipped with 500 N loading cell. During the test, each fruit was placed between the two compression plates of the machine, in a traverse orientation. The fruit was compressed steadily at a loading speed of 20 mm/min [22], until it ruptured under the compressive loading. As the compression continued, a force-deformation curve was plotted automatically, by the machine in relation to the response of each fruit to the compressive loading. From the force-deformation curve, the failure force, failure energy and deformation at failure point were extracted. The failure point (also expressed as the bio-yield point) is the point when microstructural failure of an agricultural product occurred, and it is associated with the internal disruption of the product cellular structure [23].

2.3.3 Penetration test

The Magnus Taylor Puncture Probe (MTPP), modified with Warner-Bratzler Shear (WBS) bottom platen, attached to a Universal Testing Machine (Testometric model), was used for the penetration testing. A 6 mm round-end stainless steel probe was attached to the loading cell of the Universal Testing Machine. During the test, the probe punctured and penetrated the fruit, to a pre-set depth (50% of the fruit's diameter), at a loading speed of 105 mm/min, and then the probe was swiftly removed. As the probe penetrates the fruit, a force-deformation curve is plotted by the machine, in response of the fruit tissues resistance to the puncture force. At the end of each test, the puncture force (firmness) of each eggplant fruit was mined automatically by the microprocessor of the machine, and was read from the force-deformation curve. All the eggplant fruits were tested in the traverse orientation.

According to American Society of Agricultural and Biological Engineers (ASABE) recommendations, twenty (20) eggplant fruits were used for mechanical tests [22].

2.4 Statistical Analysis

The data obtained from the laboratory tests were analyzed using the Statistical Package for Social Statistics (SPSS version 20.0), to evaluate the effect of field practice on the mechanical properties of eggplant fruit. Then the means were separated and compared by using the Duncan's Multiple Range Test (DMRT) at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Fruits Mass

The analysis of variance (ANOVA) results presented in Table 1 showed that, field practices (pre-harvest treatment) had significant ($p \leq 0.05$) effect on the mass of the eggplant fruits. The separated mean results given in Table 2 revealed that the control fruits had the least fruit mass (mean ~122.04 g); while the fruits treated with the combination of organic manure and KNO_3

recorded the highest fruit mass (mean ~167.81 g). It was observed that the fruits produced using pure organic manure had superior mass (164.96 g), over those fruits produced using pure KNO_3 fertilizer that developed average mass of 147.21 g. This depicted that although both the organic manure and KNO_3 helped to improve the growth and development of the eggplant fruits; the organic manure had a better attribute, when compared with the KNO_3 fertilizer. As shown in Table 1, there was no significant ($p \leq 0.05$) difference between the mass of fruits treated with pure organic manure, and those produced by using the combination of organic manure and KNO_3. This signified that both the organic manure and the KNO_3, contained similar essential nutrients, need by fruits for their proper development. Nitrogen and potassium are key nutrients needed by plants, to increase their yield, protein formation and resistivity to diseases [21]. Fruit mass is one of the key factors to be considered, during the design and development of fruits handling and sorting machines. According to Akaaimo and Raji [24], the mass and density of agricultural products are essential factors to be considered during the design, construction, programming, and utilization of automated agricultural products harvesting, handling and processing machines.

3.2 Compression Parameters

Failure parameters (failure force, failure energy and deformation at failure point) were considered in this study. This is because the aim of this study was to provide data for the design, development, programing and utilization of eggplant fruits harvesting and handling machines. Results presented in Figs. 1, 2 and 3 showed that field practice (pre-harvest treatment) had significant ($p \leq 0.05$) effect, on the compression parameters of the eggplant fruits. The control (T1) fruits developed the lowest failure force and failure energy; while the fruits cultivated with the combination of organic manure and KNO_3 (T4) developed the highest failure force and failure energy, with the experimental period. This portrayed that fruits produced using the combination of organic manure and KNO_3, absolved the highest compressive force and energy before failure, when compared with the fruits produced using other treatment options. Although, field practices significantly ($p \leq 0.05$) affected the compression parameters of the eggplant fruits. As revealed in Figs. 1 and 2, there was no significant difference between the failure force and failure energy of the T2 and T4 fruits.

It was observed that the fruits cultivated with pure organic manure (T2), recorded the highest deformation at failure point (24.01 mm), when compared with the T1, T3 and T4 fruits, which recorded deformation of 18.8 mm, 20.48 mm and 23.37 mm respectively. The study revealed that, the failure force of the eggplant fruits cultivated with the combination of organic manure and KNO_3 was 51.99% higher than the control fruits; 2.95% higher than the fruits produced using pure organic manure; and 28.99% higher than the fruits produced using pure KNO_3 fertilizer. Additionally, the failure energy of the fruits cultivated with the combination of organic manure and KNO_3 was 26.67% higher than the control fruits; 3.01% higher than the fruits cultivated with pure organic manure; and 21.89% higher than the fruits cultivated with pure KNO_3 fertilizer.

Table 1. ANOVA table of the effect of field practices on the mass of eggplant fruit

	Sum of squares	df	Mean square	F	P-value
Between Groups	8350.096	3	2783.365	29.556	8.12E-10*
Within Groups	3390.268	36	94.174		
Total	11740.365	39			

** = significant at (p ≤ 0.05) according to DMRT; df = degree of freedom; F = F-Statistic*

Table 2. Eggplant fruit mass

Treatment	N	Mean (g)	Std. error	Minimum (g)	Maximum (g)
T1	10	122.04^a	3.10	104.83	146.03
T2	10	164.96^c	2. 79	152.09	175.88
T3	10	147.21^b	3.43	132.53	161.24
T4	10	167.81^c	2.91	154.55	179.87

Means with similar common letter (a, b, and c) superscript in the same column did not differ significantly (p ≤ 0.05)

The increment observed in the compression parameters of the T2, T3 and T4 fruits, is attributed to the essential nutrients (potassium, calcium, nitrogen etc.), that the treatments contained, which can encouraged the production of high quality agricultural fruits and vegetables [9]. The study has indicated that during the programming and application of eggplant fruits harvesting machines, the knowledge of the crop field practices, is a key factor to be considered. This is to mechanical damage occurring to the fruits, during the process of harvesting and handling operation. According to Van Henten et al. [11], the gripper of a harvesting robot should be design and programmed so that it can grip the fruit, during the process of harvesting and conveying it to the storage point, without causing mechanical damage to it. These results will also be useful in the design of storage (packaging) structures for *Djamba* eggplant fruits. As presented in Table 2, the mean weight of *Djamba* eggplant control fruits is 1.19 N, at peak maturity stage. Therefore, a control eggplant fruit placed at the bottom of the storage box/carton can only withstand the weight of about 250 fruits; if the fruits exceeded 250, fruits arranged at the bottom of the box/container will experience failure during storage period. If the fruits are arranged in fruits liner trays, then the weight of the fruit liner trays must be subtracted from the total weight of the fruits, to be placed on top of the fruits at the bottommost layer of the storage box.

3.3 Puncture Parameter

3.3.1 Puncture force

The ANOVA results presented in Table 3 revealed that farming practice had a significant effect on the puncture force (also expressed as the fruit firmness) of *Djamba* eggplant fruits. Mean results of the fruits puncture force plotted in Fig. 4, revealed that the fruits produced with the organic manure, had the lowest puncture force at the peak maturity; while the fruits produced using the KNO_3 fertilizer had the highest fruit puncture force, within the same experimental period. Furthermore, Fig. 4 revealed that, the control fruits required an average force of 65.73 N to puncture them, which was significantly ($p \leq 0.05$) higher that the fruits produced using pure organic manure, that developed fruit puncture force of 50.30 N. This depicted that although the organic manure significantly increased the eggplant fruits growth, and ability to absolve more compressive force, it significantly reduced its puncture force.

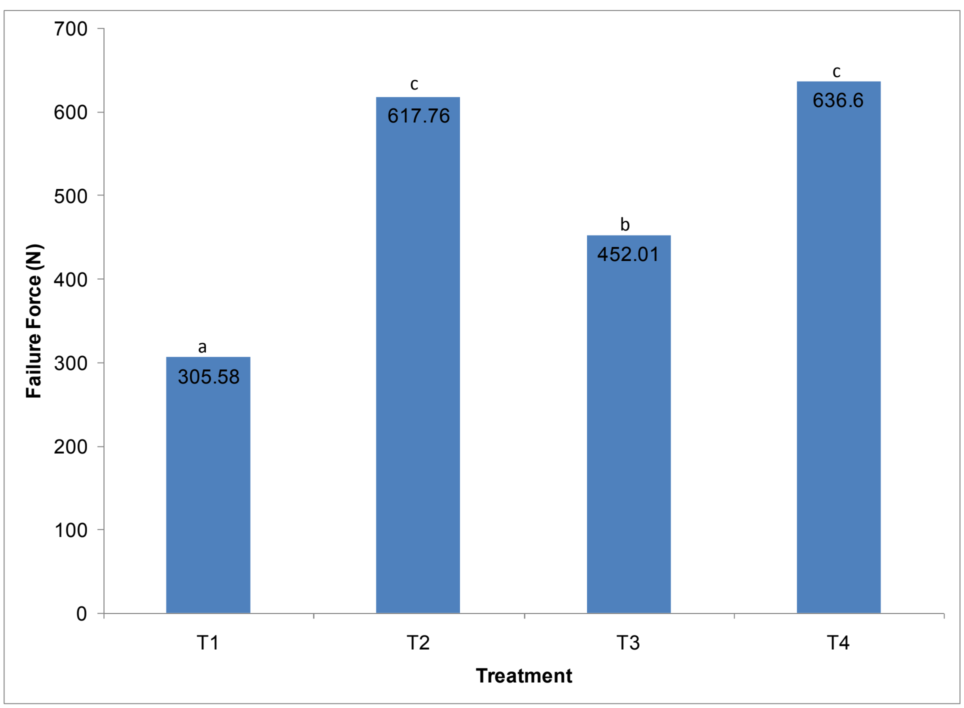

Fig. 1. Failure force of *Djamba* F1 eggplant fruit

Columns with the same common letters are not significant different at ($p \leq 0.05$) according to DMRT

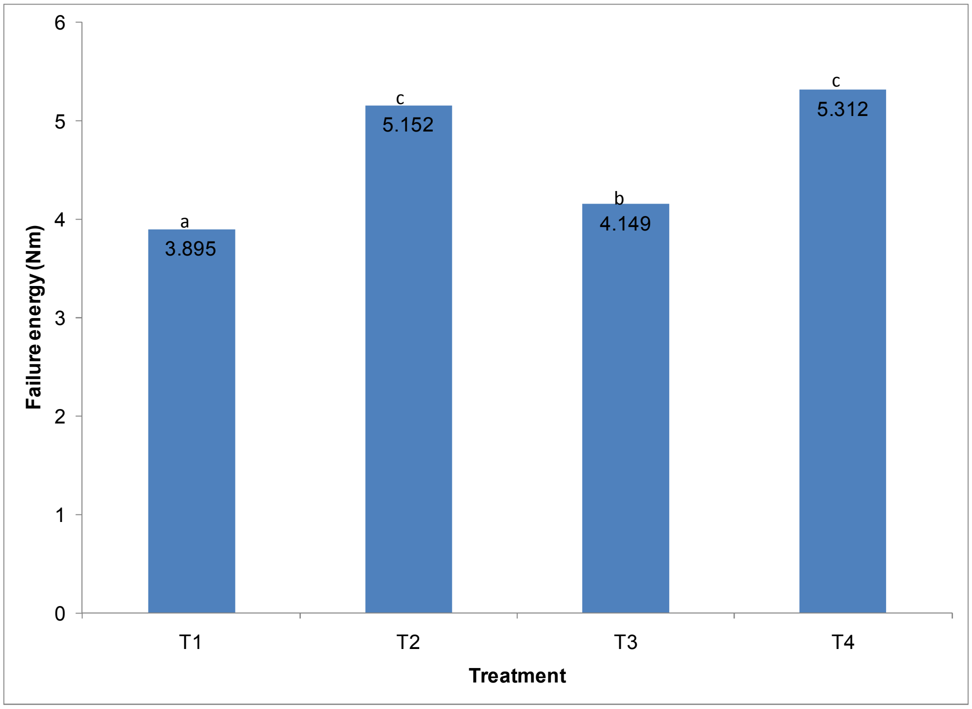

Fig. 2. Failure energy of *Djamba* F1 eggplant fruit
Columns with the same common letters are not significant different at (p ≤0.05) according to DMRT

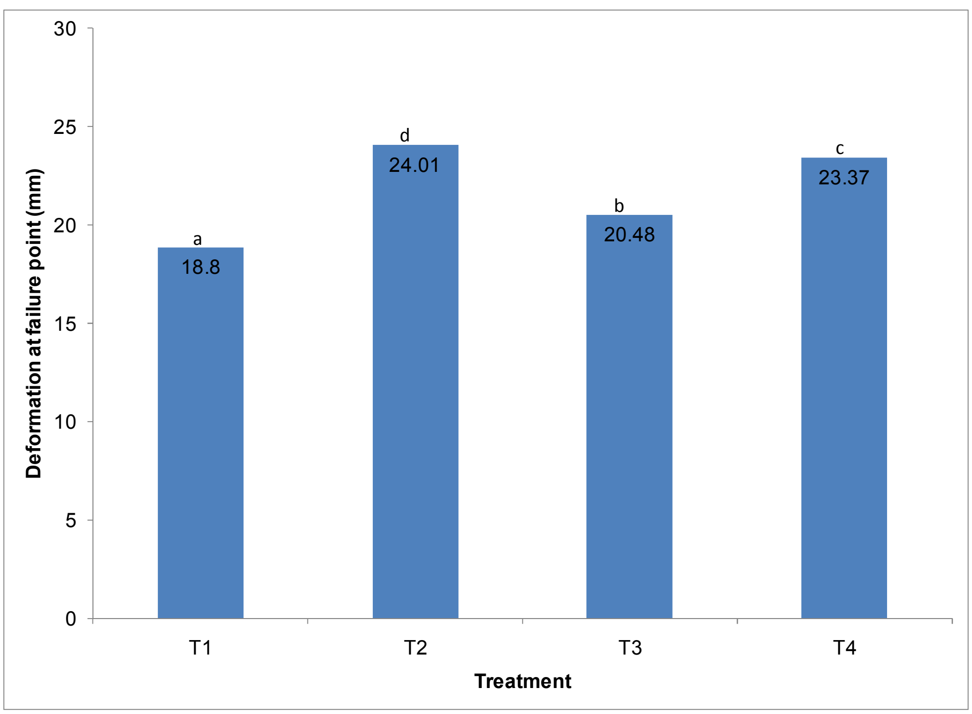

Fig. 3. Deformation at failure point of *Djamba* F1 eggplant fruit
Columns with the same common letters are not significant different at (p ≤0.05) according to DMRT

Table 3. ANOVA of the effect of f

	Sum of squares	df	Mean square	F	Sig.
Between Groups	7818.421	3	2606.140	61.955	2.73E-14*
Within Groups	1514.347	36	42.065		
Total	9332.769	39			

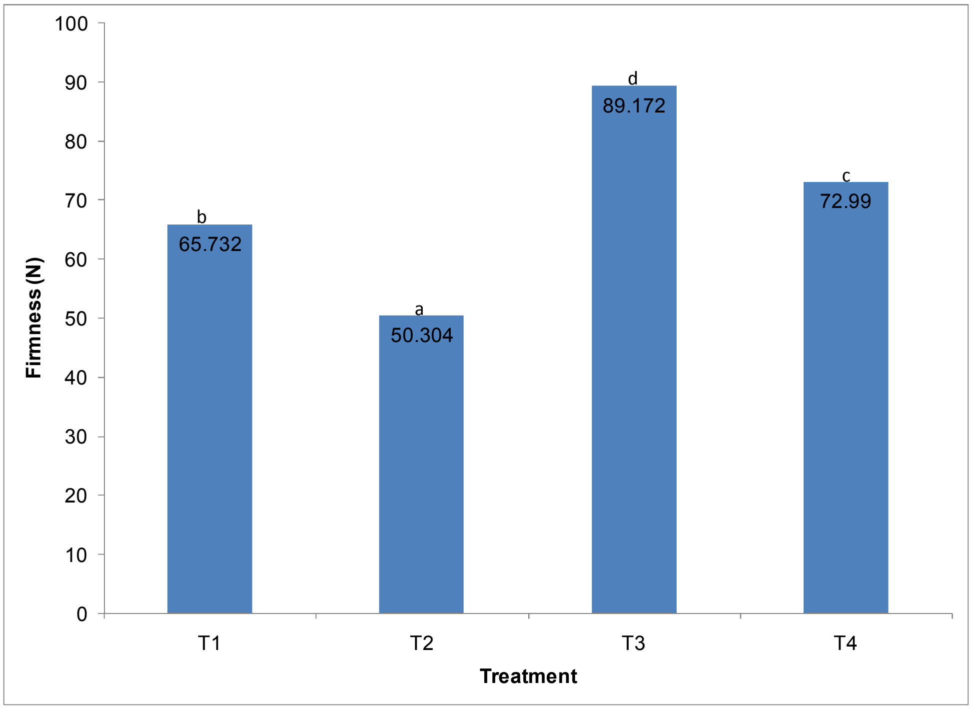

Fig. 4. Puncture force of *Djamba* F1 eggplant fruit

Columns with the same common letters are not significant different at (p ≤0.05) according to DMRT

The high puncture forces recorded in the eggplant fruits produced by using pure KNO_3, and the combination of KNO_3 and organic manure, could be attributed to the potassium content in the two treatment options. Potassium helps to calcium assimilation by plants, therefore improving the firmness of fruits and vegetables [24,25]. These results are in agreement with those earlier reported by [3,26] on pepper fruits and eggplant fruits respectively. Gajewski et al. [3] reported that cultivation medium had significant effect, on the puncture force of eggplant (cv. DRA 2086) fruits. According to [27,28], the structural and biochemical properties of agricultural products, coupled with their heterogeneous structure, greatly influenced their mechanical properties. Results obtained from this puncture test, had revealed the significance of field practices, during the design and development of eggplant fruits processing machines. Puncture force is one of the key forces that eggplant fruits are subjected to, during their handling and packaging operations; therefore, there is need for it to be managed to prevent damaging the fruits tissues which can lead to complex physiological and metabolic reactions [28,29]. Puncture force is the force required by a probe to puncture fruit tissues, causing an irreversible damage of fruit [30]. Emadi [31] stated that apart from food wastage, adequate knowledge of the mechanical behaviour of agricultural products, helps to reduce the energy and power wastage during their handling and processing operations; therefore optimizing the efficiency of the handling and processing machines [20].

4. CONCLUSION

The study evaluated the effect of field practices on the optimization of agricultural products harvesting and handling machines. The *Djamba* F1 eggplant was subjected to four different pre-harvest treatments; which were control, organic manure, potassium nitrate and the combination of organic manure and potassium nitrate. Laboratory tests on the fruits harvested from the eggplants indicated that, field practices had significant effect on the mechanical properties of the *Djamba* F1 eggplant fruit. The Control fruits developed the least body mass (122.04 g); while the fruits produced by using combination of organic manure and KNO_3 developed the highest body mass of 167.81 g. It was observed that the fruits produced by using combination of organic manure and KNO_3, exhibited superior failure force and failure energy, over the Control fruits and the fruits produced by using pure organic manure and pure KNO_3. Likewise, the study revealed that the fruits cultivated with pure organic manure had the poorest puncture force (50.30 N), which was lowered than the 65.73 N recorded by the Control fruits. These results signified the importance of the knowledge of field practices, during the programming and application of agricultural products harvesting and handling machines, to avoid mechanical damages, which will lead to food wastage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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